REPLACEMENT SHEET

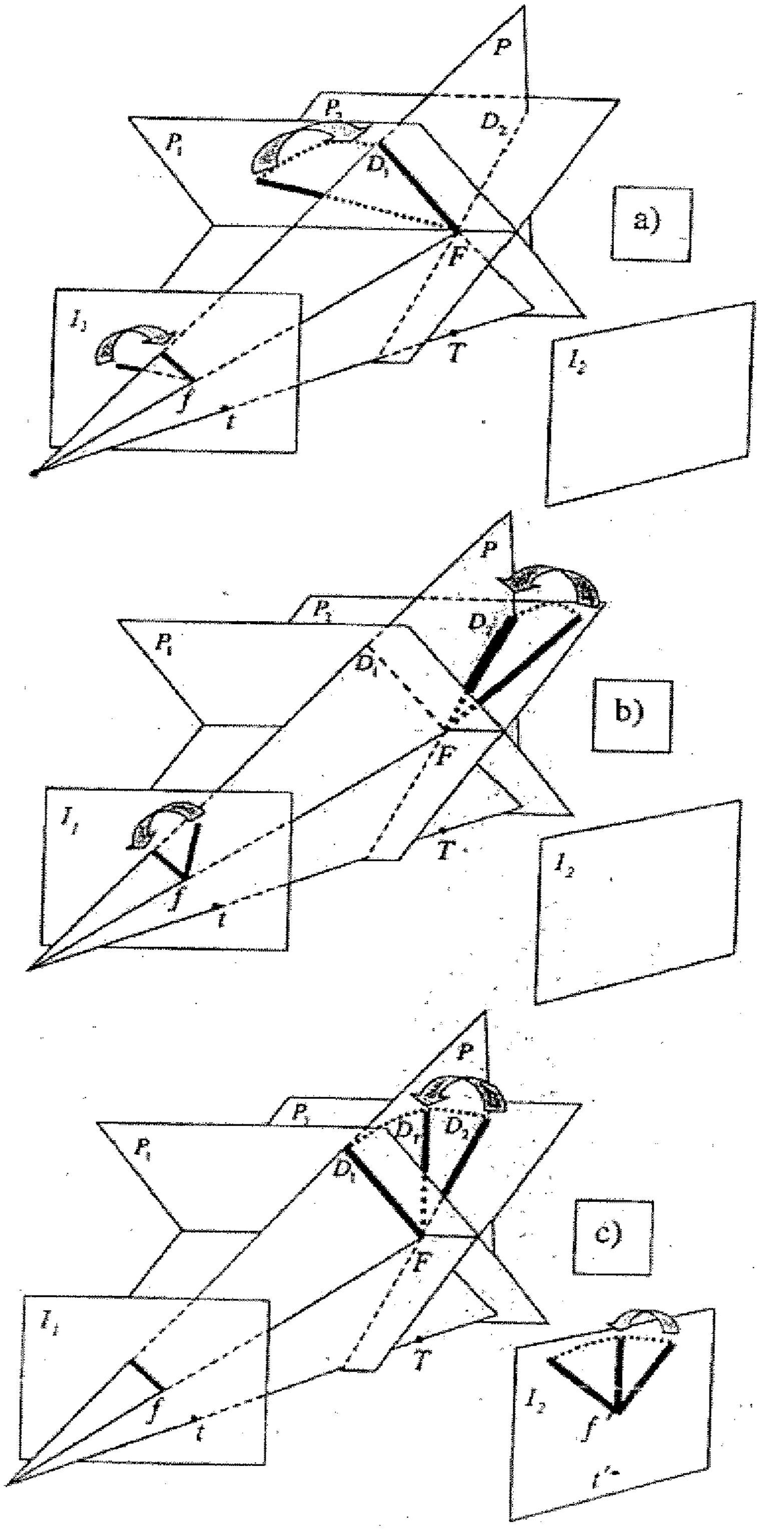


Fig. 1: Needle Placement by visual Servoing in 3 Successive Planes using 2 views

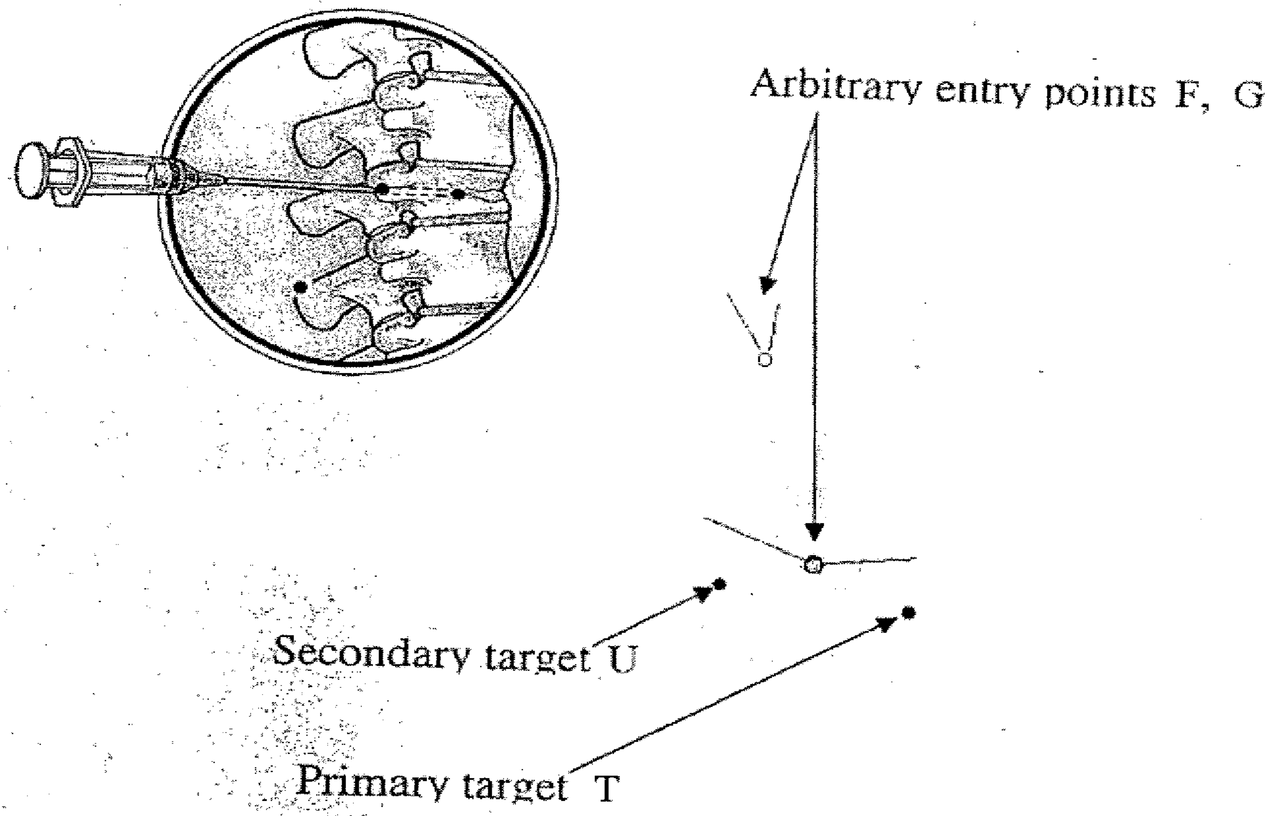


Fig. 4 Best entry point to reach one target by passing through secondary target. It can be found by first orienting the needle to the targets from 2 arbitrary entry points

FIGURE 7

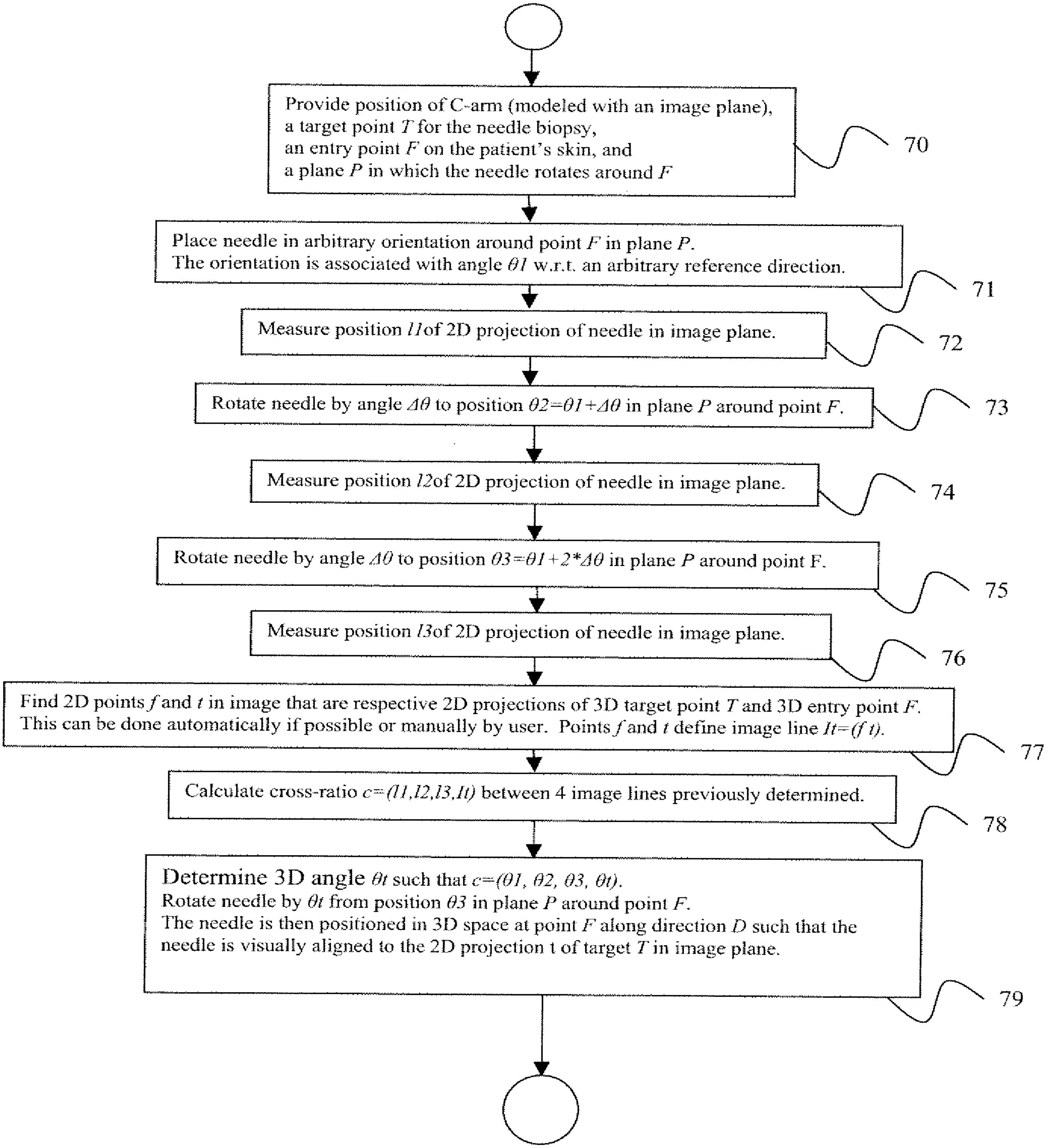
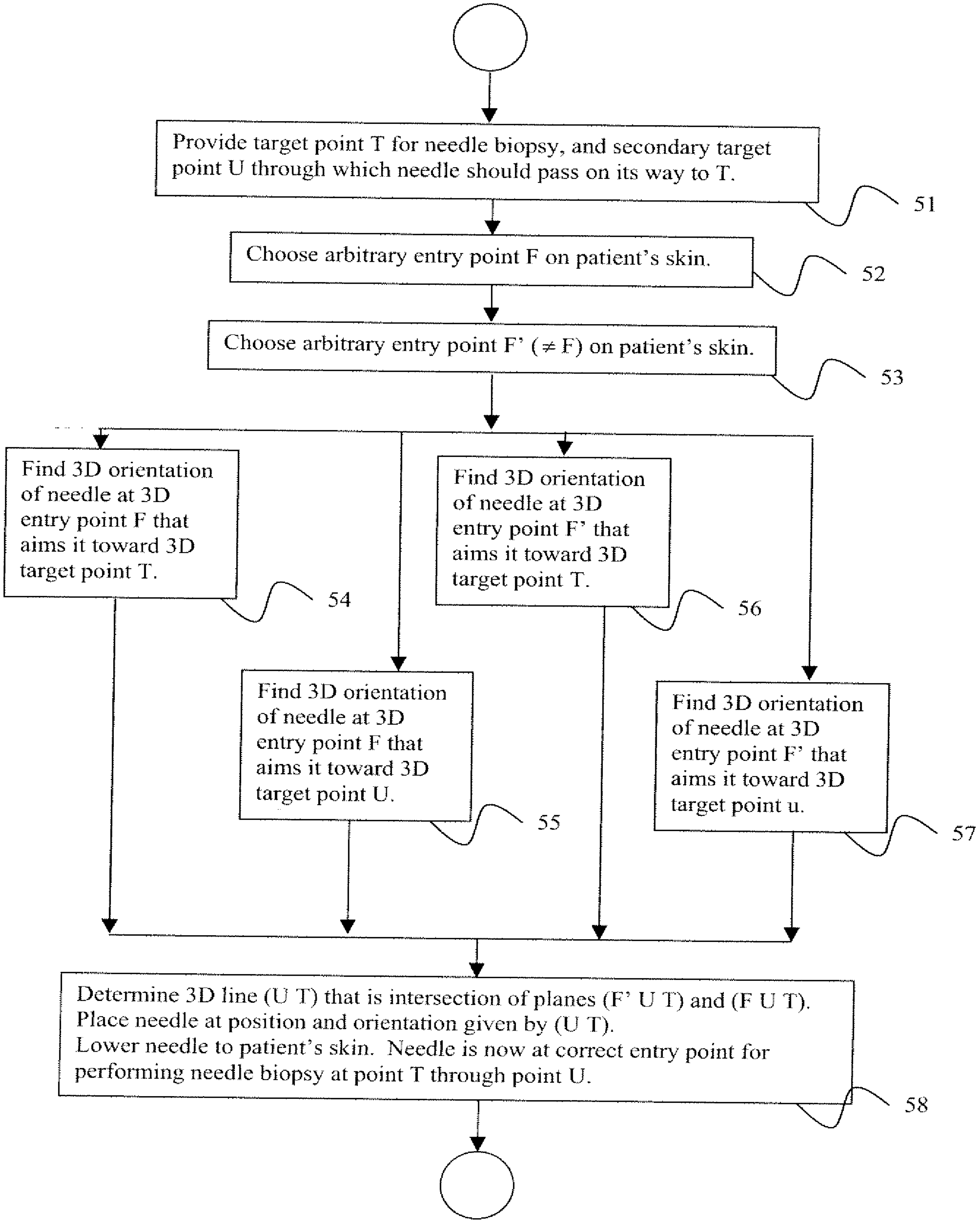

Provide position of C-arm (modeled with an image plane), a target point T for the needle biopsy, an entry point F on the patient's skin, and a plane P in which the needle rotates around F
70
Place needle in arbitrary orientation around point F in plane P. The orientation is associated with angle $\theta 1$ w.r.t. an arbitrary reference direction.
71
Measure position $l1$ of 2D projection of needle in image plane.
72
Rotate needle by angle $\Delta\theta$ to position $\theta 2=\theta 1+\Delta\theta$ in plane P around point F.
73
Measure position $l2$ of 2D projection of needle in image plane.
74
Rotate needle by angle $\Delta\theta$ to position $\theta 3=\theta 1+2*\Delta\theta$ in plane P around point F.
75
Measure position $l3$ of 2D projection of needle in image plane.
76
Find 2D points f and t in image that are respective 2D projections of 3D target point T and 3D entry point F. This can be done automatically if possible or manually by user. Points f and t define image line $lt=(f\ t)$.
77
Calculate cross-ratio $c=(l1,l2,l3,lt)$ between 4 image lines previously determined.
78
Determine 3D angle θt such that $c=(\theta 1, \theta 2, \theta 3, \theta t)$. Rotate needle by θt from position $\theta 3$ in plane P around point F. The needle is then positioned in 3D space at point F along direction D such that the needle is visually aligned to the 2D projection t of target T in image plane.
79

FIGURE 5


Provide target point T for needle biopsy, and secondary target point U through which needle should pass on its way to T.
51
Choose arbitrary entry point F on patient's skin.
52
Choose arbitrary entry point F' (≠ F) on patient's skin.
53
Find 3D orientation of needle at 3D entry point F that aims it toward 3D target point T.
54
Find 3D orientation of needle at 3D entry point F that aims it toward 3D target point U.
55
Find 3D orientation of needle at 3D entry point F' that aims it toward 3D target point T.
56
Find 3D orientation of needle at 3D entry point F' that aims it toward 3D target point u.
57
Determine 3D line (U T) that is intersection of planes (F' U T) and (F U T). Place needle at position and orientation given by (U T). Lower needle to patient's skin. Needle is now at correct entry point for performing needle biopsy at point T through point U.
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